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NATIONAL BUREAU OF STANDARDS REPORT

10 870

FIELD MEASUREMENT OF HCl CONCENTRATION FROM PVC ELECTRICAL CONDUIT INVOLVED IN FIRE

SINGLE STORY HOUSE

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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SINGLE STORY HOUSE

February 4, 1972

by
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ABSTRACT

An experimental fire test was conducted to examine the potential development and spread of HCℓ in a 5-room house containing an installation of PVC and EMT electrical conduits. The fire load was about 3.2 lb/ft^2 in the form of a wood crib in a small room. The fire involved 16 ft. of nominal 3/4" PVC conduit loaded with six 14-gage PVC insulated copper wires and 7 ft. of nominal 3/4" EMT conduit similarly loaded. Temperature, smoke and HCℓ concentration profiles in several rooms were obtained. Maximum HCℓ and smoke levels in a room adjacent to the fire were 85 ppm and about 0.6 OD/ft respectively.

The HCℓ concentration in adjacent rooms from burned PVC conduit was estimated to be about two times that from EMT of equal length containing the same number of PVC insulated wires. The relative low HCℓ from the PVC conduit was due in part to a blockage of the conduit core opening by the charred residue of the themoplastic conduit and wires as well as by HCℓ absorption losses.

1.0 Introduction

To examine the potential development and spread of $HC\ell$ from PVC-insulated wire and electrical conduit exposed to fire, a field fire test was conducted in a single story house in Montgomery County, Maryland on February 4, 1972. The house, a recently vacated wood clapboard structure scheduled for demolition, was made available by the Montgomery County Fire Department.

The purpose of the test was to supplement the results from a previous test [1] by collecting additional information under different experimental conditions. The object of the test was to determine to what extent a fire in a room containing exposed electrical PVC conduit and insulated wiring would generate and spread the primary combustion product, $HC\ell$ to adjoining rooms through the conduit system.

Some experimental conditions of this test differed from that of the previous one. For example all conduits used in this test contained within them standard insulated copper wires. Another type of conduit, EMT (Electrical Metallic Tubing), was also included in this test. The combustible load in the fire room was more typical of that found in residential occupancies. Spread of $HC\ell$ as well as smoke was monitored during this experiment.

2.0 Material and Construction

Fig. 1, 2, and 3 shows the dimensions and location of rooms in the test house. The house was essentially a one-story 27 x 21 foot painted wood shingle frame structure on a cinder block foundation. It consisted of 4 rooms and a bathroom. Only three rooms and the bathroom used in the test are shown in Fig. 3.

The bathroom with its fixtures, i.e. sink, tub, toilet, window, and door removed was converted into a fire room. Its interior surfaces including floor and window were covered by 2 layers of 5/8" thick type "X" gypsum board. The final room size was 8.3' x 4.3' x 7.5' (height). Framed by gypsum board, the window and door openings were 2' x 1.5' and 3.7' x 2' respectively.

The upper half of the door opening was covered with gypsum board in an attempt to limit the rapid escape of the combustion products into Room D.

The other rooms in the test house were not modified except for gypsum board in the hall. The walls and ceilings of Rooms A, B and C were painted 3/8 inch thick gypsum wall board. The floors consisted of varnished 2 1/4 inch width tongue and groove oak flooring. Each room had two double-hung, 48" x 40" wooden sash windows. All rooms except the fire room were empty, with doors and windows closed during the test, except for the hallway entrance door in Room D. This served as a means of cross ventilated air supply for the fire room.

2.2 PVC and EMT conduits

Nominal 3/4" ID PVC (Polyvinyl Chloride), 3/4" CARLON "CONDUIT 40" NEMA, TC2, CAT 49007 and nominal 3/4" steel EMT HR811 commercial electrical conduits were used. The PVC conduit was a rigid plastic piping gray in color, 13/16" ID, 1/8" wall thickness and weight 0.23 lb/ft. The EMT was a galvanized steel pipe, 13/16" ID, 1/16" wall thickness and weight 0.47 lb/ft. Couplings and fittings of the same material were used as required for connection to junction and outlet boxes. The inside cross sectional area of a 13/16" ID pipe is 0.52 in^2.

To simulate a realistic field installation and to prevent premature collapse of the thermoplastic conduit in the fire, all conduits contained within them six (6) 14-gage PVC insulated copper wires of the standard 14 1W 600 (UL) type. The unit weight of insulation of the wire bundle was 0.034 lb/ft or about 15% of the conduit weight. The six wires extended the full length of the conduit system in both type of conduit to junction boxes, switches and fixtures. The wires occupied 14.2% of the inside area of the conduit, leaving 0.45 in^2 of open area through which smoke and gases could presumably travel.

2.3 Junction Boxes, Switches, and Fixtures

The location of junction boxes, switches and light fixtures is shown in Fig. 3. The junction and outlet boxes for light switches were of the common residential type, 4" x 2 1/8" x 1 7/8", galvanized steel construction. Switches and light fixtures were also the type used in common residential houses. All boxes, switches and light fixtures were connected with 2 wires and had covers simulating normal installation. The other 4 of the 6 wires terminated in the box or fixture without connection. The two lamp fixtures in the fire room included 8 inch diameter glass covers, but without light bulbs.

2.4 Conduit Layout

Fig. 3 shows the layout of the PVC and EMT conduits in the test. The PVC system ran from a switch, 4 ft. above the floor at the middle of the east wall of the fire room, vertically to the ceiling where it turned 90° and proceeded to the middle of the ceiling, where it connected to a junction box with a lamp fixture. The conduit then continued along the ceiling and penetrated the west wall of the fire room into a ceiling junction box in Room A. From the junction box, one branch proceeded downward at the wall to a box and switch located 4 ft. above the floor, the other branch continued along the ceiling and penetrated the west wall of the fire room into a ceiling junction box in Room A. From the junction box, one branch proceeded downward at the wall to a box and switch located 4 ft. above the floor, the other branch continued along the ceiling to the middle of the ceiling where a junction box with lamp fixtures was located. The conduit made a 90° turn at the box and continued along the ceiling to the south wall of Room A. It penetrated the wall into a junction box at the ceiling of Room B. From the junction box, one branch proceeded downward at the wall to a switch located 4 feet above the floor, the other branch continued along the ceiling to the middle, where the junction box with a lamp fixture was located. The conduit then made a 90 degree turn at the box and proceeded along the ceiling and then down the wall to a switch.

Two other short PVC conduit systems started at the east wall along the ceiling of the fire room and proceeded toward the west wall, penetrated the wall into Room A, made a 90 degree turn down the wall and each terminated at a junction box with switch located 4 feet above the floor.

The EMT system started from a switch located 4 feet above the floor at the west wall of the fire room and proceeded to the ceiling, bent 90 degrees and proceeded to the middle of the ceiling where a junction box with light fixture and glass cover was located. It then continued along the ceilin penetrating the east wall into the adjacent Room C where it was connected into a covered junction box mounted on the ceiling. From the junction box, one branch proceeded downward at the wall to a switch box, located 4 feet above the floor; the other proceeded along the ceiling to a junction box with lamp fixture at the middle of the ceiling.

A total of about 16 feet of PVC conduit and 96 feet of PVC insulated 14 gauge copper wire within the conduit were used in the fire room. Also included in the fire room were 7.3 feet of EMT and 44 feet of PVC insulated wire.

Extraneous gas leakage between rooms was minimized by caulking the openings through which the conduit pierced the walls with plaster.

2.5 Wood Crib

The only contents of the fire room were a 3' x 2' x 2.3' wooden crib constructed by stacking 27-inch long pieces of nominal 2" x 4" white pine sticks. The crib, representing combustible contents, weighed 113 pounds. It was supported 5 inches above the floor by two cinder blocks. About three pounds of 1" x 1" x 24" white pine and 0.3 quart of kerosene were used to initiate the fire. The combustible load in the room was 3.2 pounds per square foot of floor area and 0.43 pounds per cubic foot of volume.

3.0 MEASUREMENTS

3.1 HCℓ Sampling

Indications of the HCℓ concentration were obtained in the adjacent rooms A, B, and C by the use of Drager colorimetric indicator tubes. These tubes indicate HCℓ concentration by a pre-calibrated length of color stain when a known volume of gas is drawn through the tube using a manually operated hand pump. The indicator tubes were positioned near the center of each room. A hollow rigid horizontal tube passed through an opening in the exterior wall into the center of the room and provided support for remote pumping and easy retrieval and replacement of the indicator tubes. In the very early stages of the fire, an observer inside the rooms also performed gas sampling near the outlet boxes.

3.2 Temperature Measurements

Twelve thermocouples located within the fire and other rooms were used to monitor continuously the temperature profile of the fire. Figure 3 and 4 shows some thermocouple locations and selected time temperature profiles developed during the test, respectively.

3.3 Smoke and Gas Measurements

Continuous monitoring of smoke build up was conducted in Room A and Room B by the use of photoelectric smoke meters and in Room C by observation. Two smoke meters were located in Room A. Smoke Meter SM-2, located 8 inches from the middle of the east wall, covered a folded vertical path length of 13.3 feet from a light source 16 inches above the floor to a mirror mounted on the ceiling and back to the photodetector next to the light source. The other Smoke Meter, SM-1, located in the center of Room A covered a vertical path length of 1.5 feet at the midheight of the room.

Another smoke meter, SM-3, was located 8 inches from the middle of the north wall in Room B, covering a folded vertical path length of 13.3 feet.

Due to a last minute break down of monitoring equipment, CO and O_2 concentration measurements were not obtained.

3.4 Observations

Motion pictures of the fire room recorded graphic information on the deflection and melting of the conduit and behavior of the fire. An observer stationed outside the window took note of events in the fire room.

3.5 Short Conduit

To compare the time required for circuit failure in the fire room in both the PVC and EMT conduits, two separate active circuits were used. A 67.5 V battery was connected between a single wire and the other five wires in parallel inside both the main PVC and EMT conduit systems. A recorder monitored the voltage drop across the terminal of the battery. A short between the single wire and any of the other wires was indicated by a sudden voltage drop on the recorder.

4.0 RESULTS AND DISCUSSION

The primary interest of this experiment was the thermal and electrical behavior of the conduit system and the magnitude of the HCℓ spread through the conduit to other rooms. At about 1.5 minutes, the PVC conduit along the ceiling directly over the fire began to soften and generate smoke. An electrical short in the wiring in the PVC and EMT conduits occurred prior to this, at 1.0 and 1.2 minutes, respectively. It is impossible to pinpoint the region in which the wire shorted; it is most likely that it occurred in the region directly above the fire rather than at the switch area. Thermocouple readings at 1.5 minutes showed that temperature at the center of the room, 8 inches below the ceiling was about 400°C. This was 40°C higher than the temperature 8 inches from the wall along the PVC conduit near the switch. Before shorting completely, the resistance between the wires dropped gradually during a 0.2 minute period. This indicates melting of the PVC insulation of the wires.

At about 4 minutes, there was insufficient air flow into the fireroom as evidenced by the smoke exhaust and drop in fire room temperature. To remedy this, the board across the window at the exterior of the fire room was removed, doubling the original opening. The door in Room D to the outside porch was also opened. The fire resumed active burning as indicated by momentary temperature rise shown in Figure 4.

Because of the intensity of the fire in the fire room, practically all PVC conduit and wire insulation was decomposed leaving only a small amount of charred residue and bare copper wire. The maximum temperature reached was 850°C. The copper wire (melting point about 1100°C) did not melt. Where the conduit pierced a wall into another room, the charred residue from the thermoplastic conduit and internal wiring effectively blocked most of the smoke and gas movement through the conduit. The conduit in the adjoining rooms was almost unaffected with no signs of softening or charring. The detail of this is shown in Figure 5.

The EMT conduit in the fire room was intact though the PVC insulation of the wiring inside was charred.

Smoke was observed emanating from the junction and switch boxes in Room A in about 1.2 minutes. Figure 6 shows the smoke build-up as recorded by the smoke meters located in Rooms A and B. The smoke reached a maximum plateau of about 0.6 OD/ft* in the center of the room at about 7 minutes. The peaking time also matched the one based on HCℓ concentration measurement.

HCℓ concentration measurements were recorded periodically from the center of each room. Figure 7 shows measured HCℓ concentration at each room during the test. The maximum level was 85 ppm in Room A; 25 and 15 in Rooms B and C respectively.

The HCℓ found in Room C was primarily from the decomposition of PVC wire insulation inside the EMT conduit in the fire room. Since the integrity of the conduit was intact, the combustion products from the insulated wires, except for absorption losses, were conducted by the conduit to Room C. On the other hand, the decomposition products from the wire insulation in the PVC conduit, and from the conduit itself, spilled into the fire room as the conduit burned and collapsed. The charred residue at the opening of the unburned section of the PVC conduit in the wall of Room A tended to block the flow of gas and smoke through the conduit.

The higher PVC loading of 4.2 lb (from 16 feet of conduit and wire insulation) for the PVC conduit may be compared to 0.25 lb (7.3 feet of insulation) for EMT in the fire room. Despite the relative loading of 16 times, the ratio of the indicated HCℓ concentration in Room A plus Room B relative to Room C did not exceed a factor of 7.2. All room sizes were approximately equal.

Another comparison between PVC and EMT conduit may be based on concentration of HCℓ found in Room B and Room C. The HCℓ in these two rooms was generated from systems of comparable length (7.3 feet) in the fire room. The maximum HCℓ from the PVC conduit system, after losses in passing through a 10 foot section of the conduit in Room A, was about 1.7 times higher than that found in Room C from the EMT system. This did not consider losses resulting from unequal length of additional conduits the gas might travel to reach junction boxes within Room B or Room C.

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* Optical Density per foot.

In assessing HCℓ and smoke movement, it should be pointed out that HCℓ decays rather rapidly by absorption on solid surfaces. Undoubtedly much HCℓ is lost passing through the conduit where surface area including the insulated wire was 60 in^2/ft. A simple laboratory study could determine the losses per unit length. The decay portion of the curve in Figure 7 shows the relative ease with which HCℓ vapor in the room is lost, after 8 minutes, when HCℓ is no longer available from the fire room. Since the rooms were unusually cold ($60^{o}F$), the loss rate was probably higher than might be expected at higher ambient temperature.

The maximum HCℓ measured in Room A and B represents only about 0.4% of the potential HCℓ from the PVC conduit loading in the Fire Room assuming no losses. The HCℓ measured in Room C represents about 1.1% of the potential HCℓ from PVC insulation in the EMT system.

5.0 CONCLUSIONS

1. A room fire involving the burnout of about 3 lb/ft^2 of combustible contents is likely to burn or char all the thermoplastic insulation on electrical wiring in exposed plastic or metallic electrical conduit.
2. The HCℓ concentration in an adjacent room (85 ppm) was not as high as might be expected from a test situation where combustion pressure could presumably force the gaseous products directly through available open area within the conduit (85% open for the condition tested).

3. The expansion and charring (intumescent) nature of PVC electrical conduit may serve to seal the interior conduit openings against extensive HCℓ penetration of an otherwise sealed wall. Sealing of the wall opening around the exterior of the conduit with noncombustible material is important.
4. The maximum HCℓ measured in two rooms with PVC conduits represents only about 0.4% of the potential HCℓ from burned conduit systems assuming no losses.
5. Information on the CO and O_2 concentrations in the adjacent rooms is missing due to an equipment malfunction at the start of the test.
6. Because of blockage from charred section, and the deposition of vapors in passing through 10 foot section of PVC conduit, the HCℓ concentration level from the PVC conduit source was of the same order of magnitude as that from the EMT source. Both generating sources were 7.3 feet in length.

6.0 REFERENCE

T. G. Lee, NBS Report 10483, Field Measurement of HCℓ Concentration from PVC Electrical Conduit Involved in Fire, September 1971.

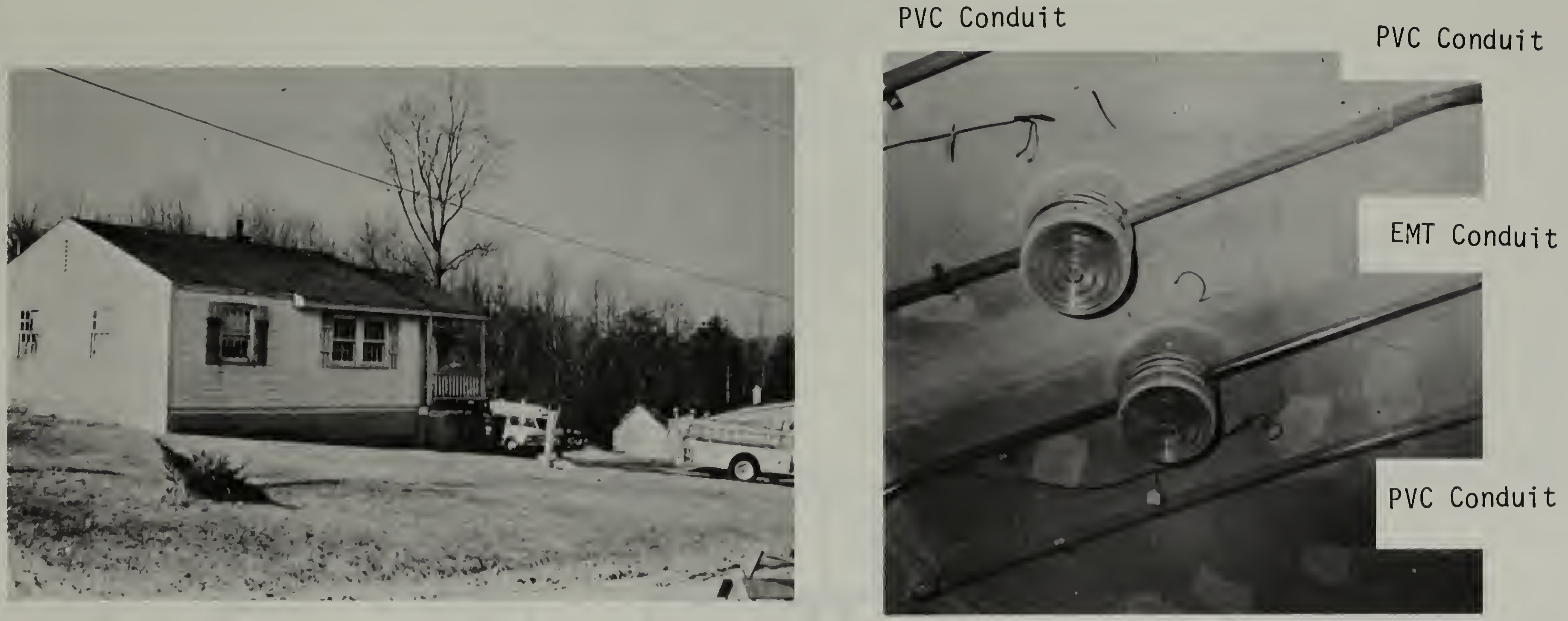

Fig. 1 Photograph of Test House (front, Room B and D) and Ceiling of Fire Room

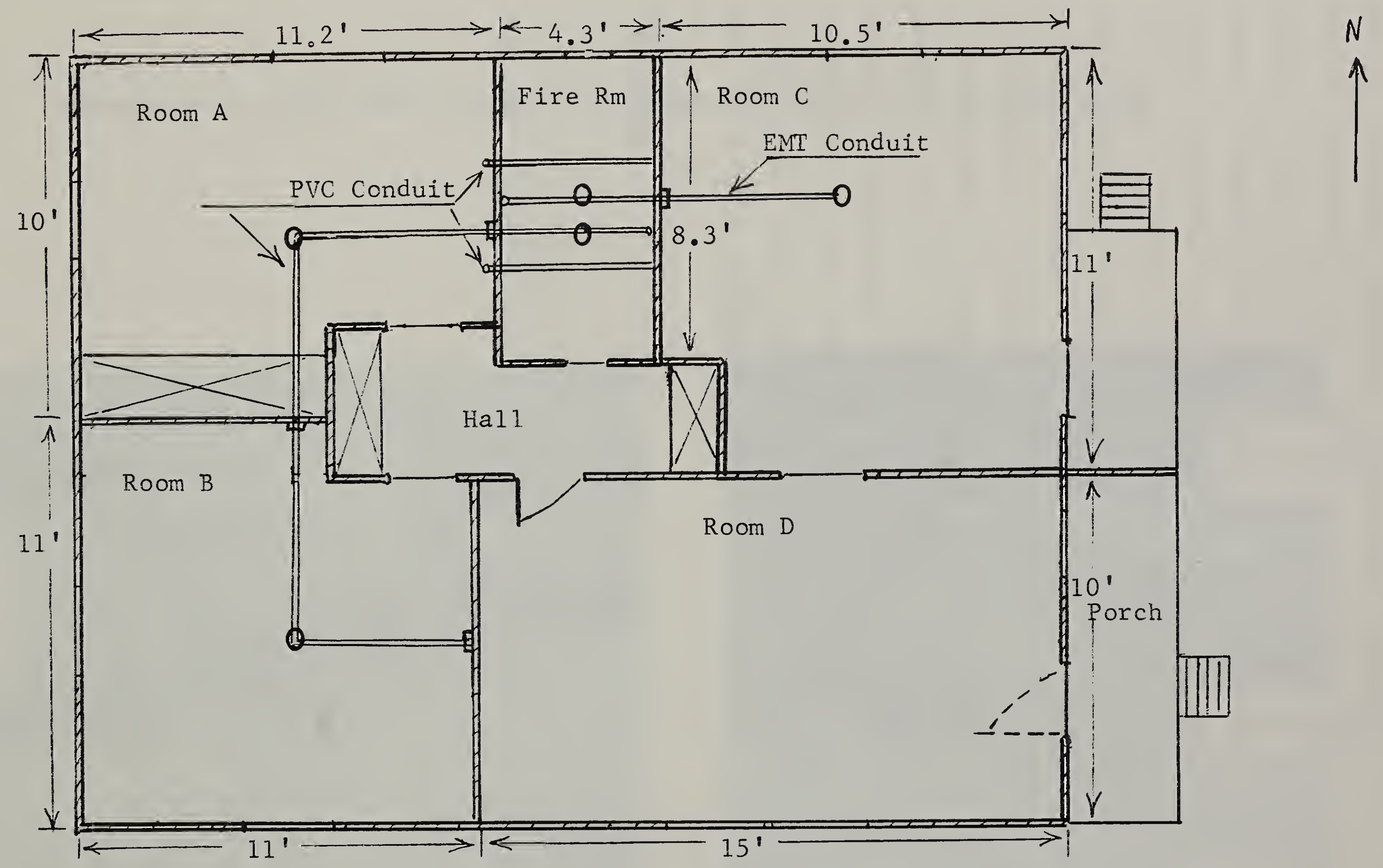

Fig. 2 Locations of PVC and EMT Conduits in Test House

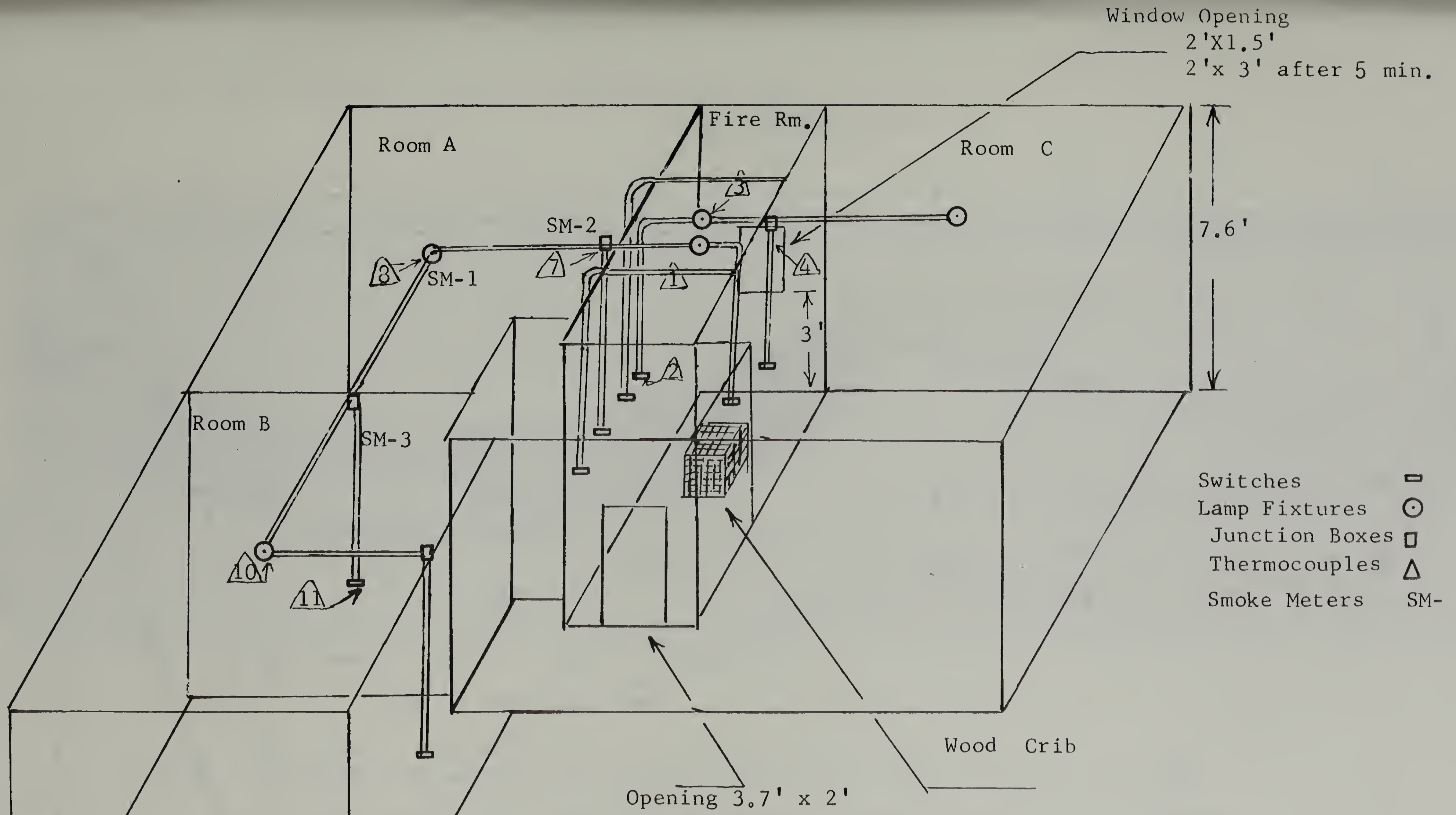

Fig. 3 Conduit Layout in Test House

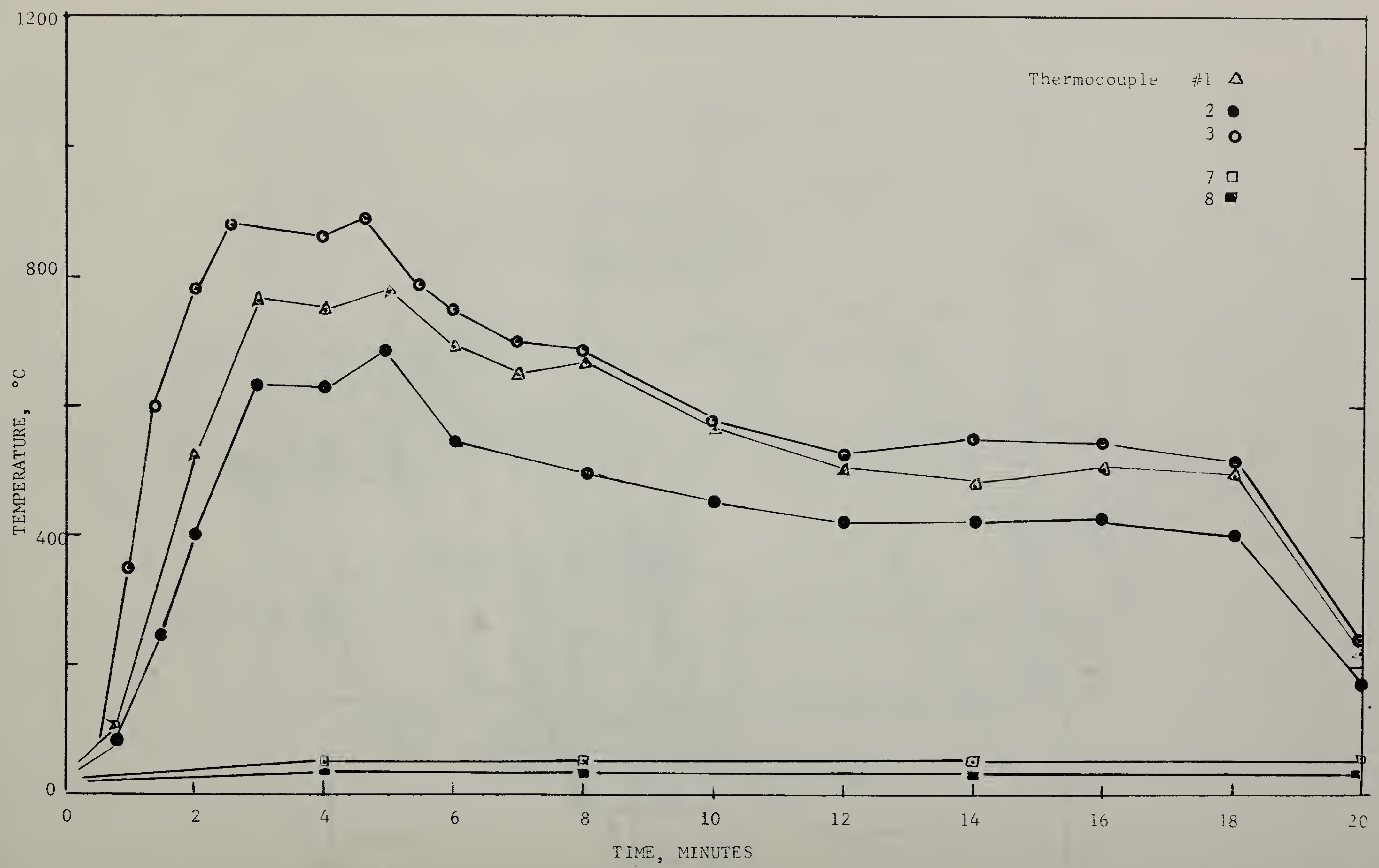

Fig. 4 Time-Temperature Profile of Fire and Other Rooms

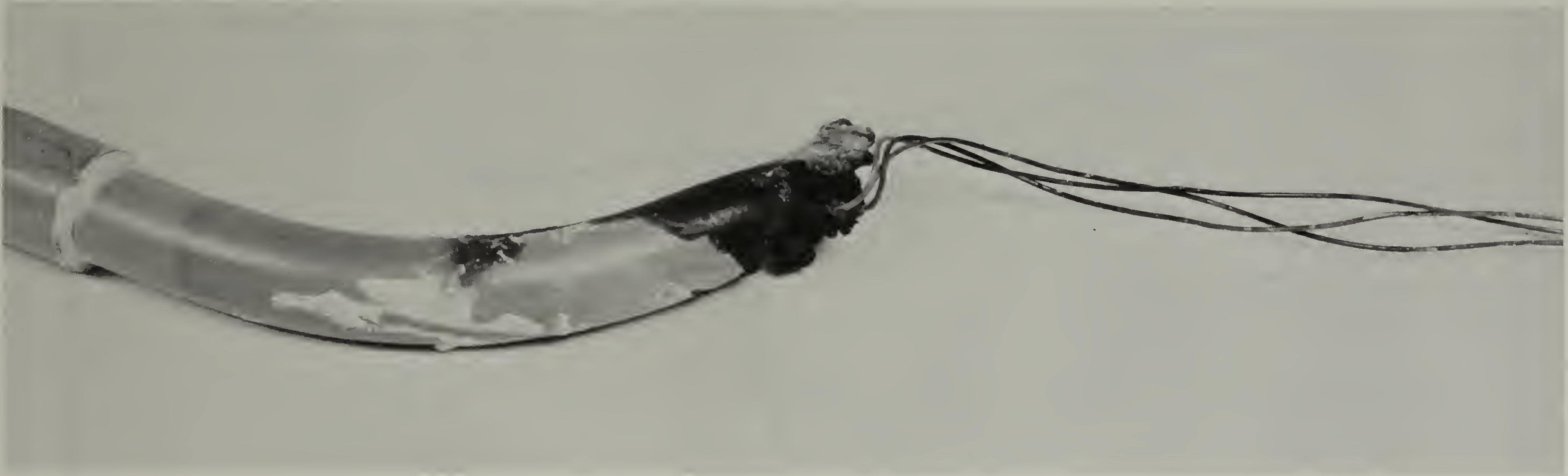

Fig. 5 PVC Conduit at Intersection of the Wall Between Room A and the Fire Room (Note charred residue and complete decomposition of conduit and insulation at the burned end. Some wires were removed)

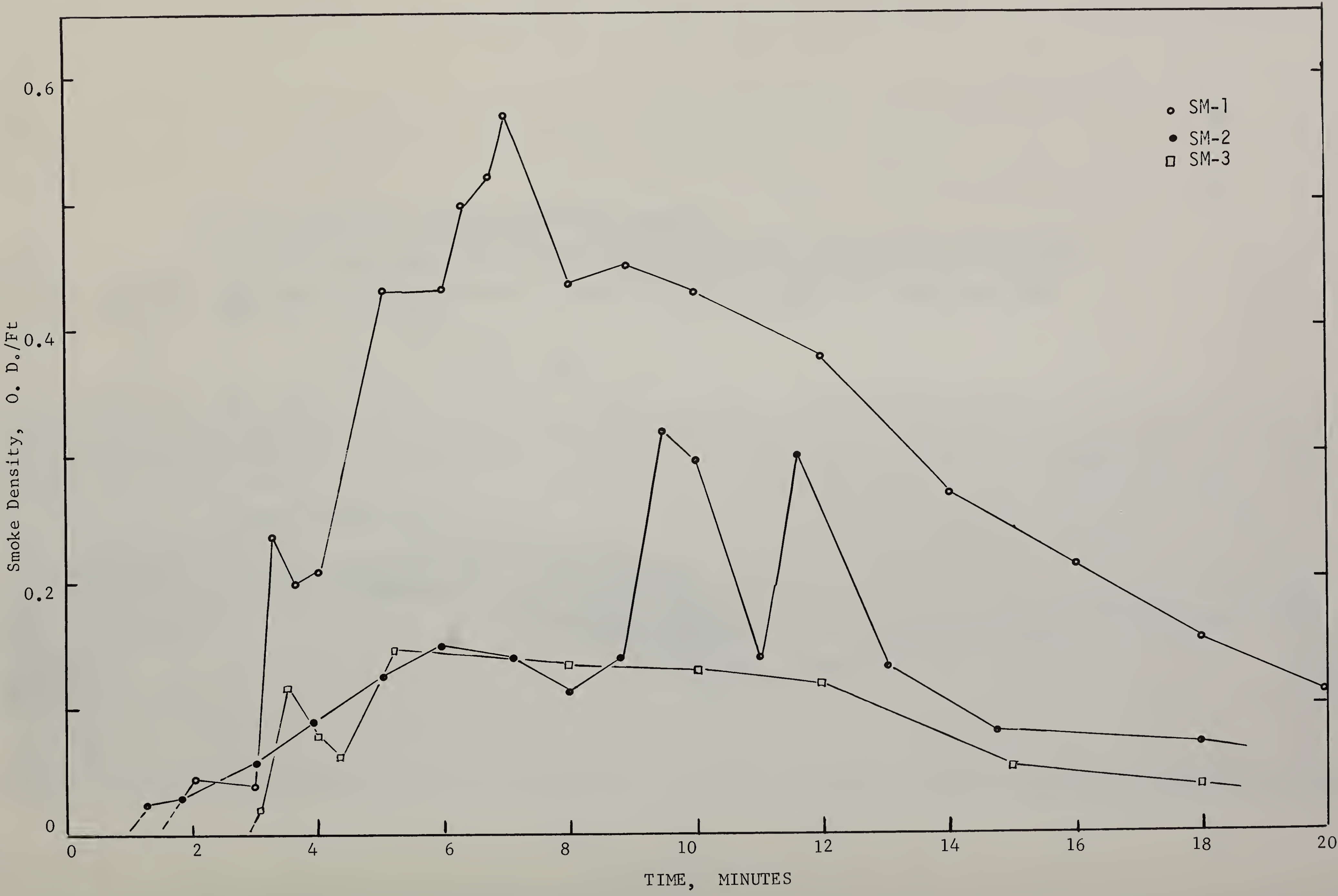

Fig. 6 Smoke Developed in Room A and B

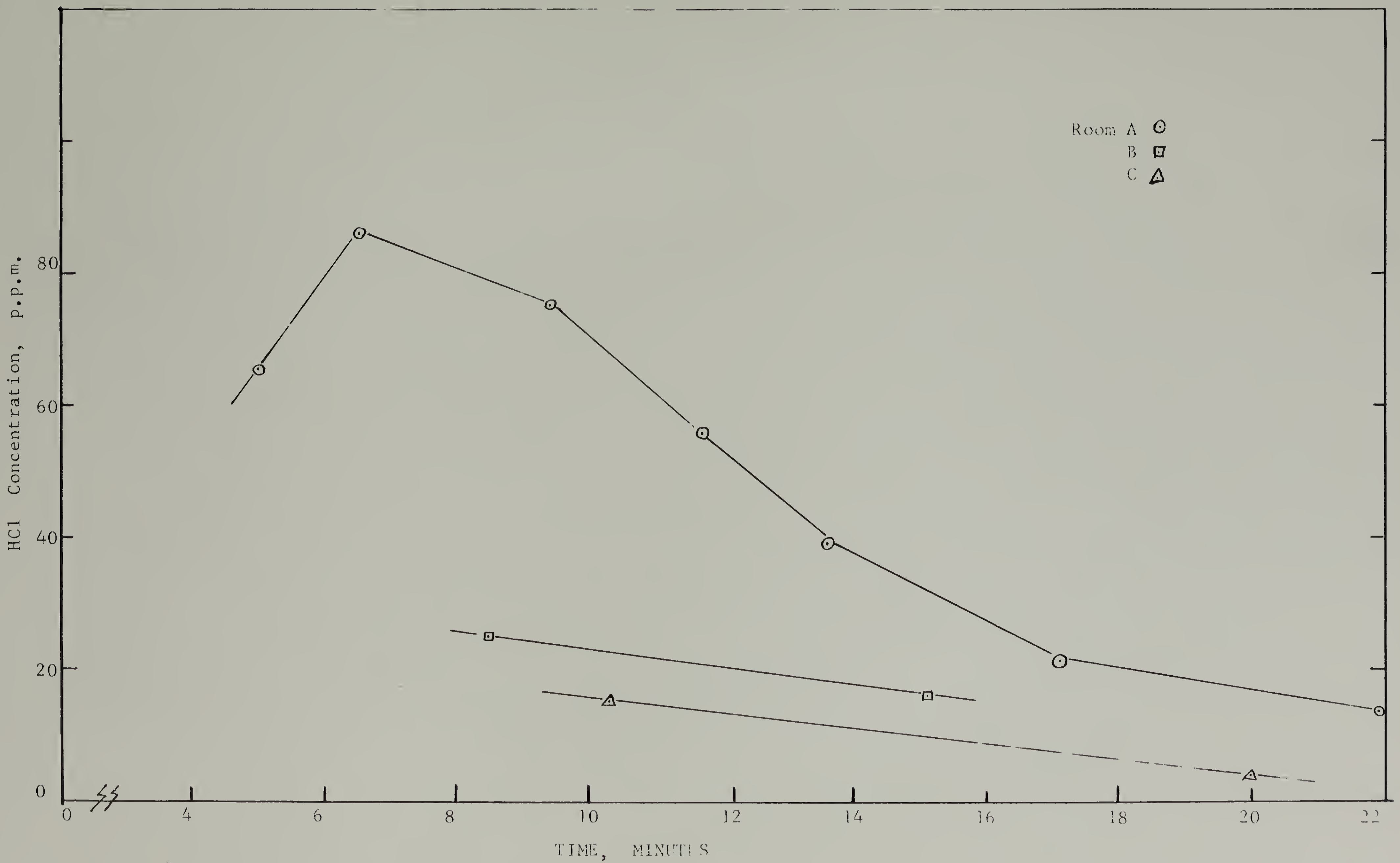

Fig. 7 Concentration of HCl in 3 Rooms

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